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USE OF NUCLEAR REACTORS FOR DISTRICT HEATING AND HEAT SUPPLY

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1. Fuel and power factors for large nuclear reactor use for district heating and centralized heat supply.

In the total fuel-power balance of the USSR electric power constitutes about 15% at present and total electrification having been carried out according to the approved plan, it will constitute about 25%. If nuclear power stations substitute a considerable number of fossil fuel-fired power plants their influence, however, on the total fuel-power balance will be comparatively not great. Nuclear fuel influence on the total fuel-power balance may and must be considerably greater if it is used not only for electricity generation but for centralized heat supply as well.

May one consider the situation usual when more than 2/3 of heat generated at nuclear power plants is lost in turbine condensers, while a great amount of coal, oil and gas is burned to get mean and low temperature heat at boilers plants? For example, in our country 1400 million hcal got due to burning high quality fuel was spent for these purposes in 1960.

Such use of high quality fuel took place during a wide development in the USSR of district heating and centralized heat supply which meet above 50% process heat and about 20% space heating demands.

Forty year experience in an extensive development of district

heating and heat supply in the USSR makes it possible to recomend these methods of using fuel as main ones for a radical rationalization of fuel-power balance, nuclear fuel sibstituting partially fossil one. In the first turn it is advisable to use nuclear fuel to meet heat supply demands in the districts where there is lack of fossil fuel or it is got at high capital and operating costs.

Nuclear reactors may be used at nuclear heating and power plants where electric power and heat are generated simultaneously as well as at nuclear district heating plants where heat is generated in the form of steam or hot water sent directly to consumers. The type of the plant must be chosen taking into consideration technical and economic factors and demands of heat consumers.

As a rule, to make the operation of heating and power plant economic a definite concentration of heat load is necessary which is 200-300 hcal/hr for a fossil fuel-fired plant, maximum electric output of the heating and power plant being 50-100 Mw.

Steam and water heat networks are used to transport heat in the USSR. The choice of a coolant and the type of heat network is determined by technical and economic considerations and depends mainly on the heat source and heat load types. To simplify the system of heat supply it is advisable to use a single coolant type for district heat loads of all kinds.

If the heat load of the district consists only of heating, ventilation and hot water supply, two-tube water heat network is usually used for district heating, the scheme of connecting it to nuclear heating and power plant is shown in Fig.1.

In the cases when in the district there is some demand for process heat besides heating, ventilation and hot water needs, process heat demand requiring heat of a higher temperature, it is advisable to use three-tube water nerworks.

In case of heat supply over long distances when heat is transported from a nuclear heating and power plant located far away from heat consumers, heat networks consisting of a single tube transit main, connecting the nuclear heating and power plant and heat using district, and two-tube distribution

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network within the district may prove to be advisable. The scheme of connecting a nuclear heating and power plant to a water network with a single tube main and two-tube distribution network is shown in Fig.2.

The studies carried out show that in case of heat supply plants using fossil fuel (no matter wether the station is of district heating or boiler plant type centralized heat supply is economic in districts where heat load density is 0.4 $\frac{hcal}{hr.ha}$ (465 $\frac{kw}{ha}$)or greater.

The progress achieved in use of new methods of centralized and local heat supply control allows to reduce significantly specific water flow rate per unit of heat load. New designs of underground heat pipes, single tube main use to transport heat over long distances should cut down significantly heat network construction capital costs and reduce operating costs. This will promote a further efficiency of district heating and centralized heat supply from nuclear and fossil fuel-fired plants.

The use of nuclear heating and power plant in the system of centralized heat supply will ensure the clearness of the air in the neghbourhood which is very difficult to achieve if coal fired heating and power plants are used even in case the most advanced methods of purifying smoke are applied.

The following special features of nuclear heating and power plant operation are to be considered while choosing its type:

1. Radiation safety of heat consumers and the personel to operate and maintain heat generators, heat networks and consumer sets.

2. The possibility of using initial low steam conditions at a nuclear plant in comparison with steam of a fossil fuel-fired heating and power plant.

3. Large capital investment in a nuclear heating and power plant may be justified if the use factor of design plant output is somewhat higher.

Radiation safety of a heat consumer may be ensured by proper choosing the steam generating plant scheme as to ensure it in the heat metwork and at consumer sets is more complex due to large water or steam flow rate.

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Initial low temperature coolant use at nuclear heating and power plant results in worsening economic characteristics of the plant but to a less degree than of a nuclear power plant with a condenser.

When at a nuclear heating and power plant standard turbines with heat extraction for heat supply and industrial purposes are used the temperature (t) of live steam should be 535°C and the pressure 90 atm.

For example, such steam conditions may be achieved in uranium-graphite reactor at the Beloyarsk nuclear power station after I.V.Kurchatov /1/.

The principal flow sheet of the unit with net electric capacity (Ne) of 100 Mw of the nuclear heating and power plant in question is shown in Fig.3.

Primary water at a pressure of 150 atm. and a temperature of 300°C is pumped into the reactor, it leaves the reactor in the form of steam-water mixture at a saturation temperature of 340°C and passes to the steam drum.

Dry steam flows to the evaporator of the steam generator where it condenses at a pressure of 150 atm. giving heat to the secondary water. The primary condensate leaves the evaporator at a temperature of 340°C, mixes with water leaving the steam drum and then enters the steam generator preheater where its temperature decreases to 300°C. In the preheater secondary feed water temperature is raised from 222°C to the saturation temperature at a pressure of 110 atm., it turns partially into steam (up to 20% by weight) and in the form of steam-water mixture is piped to the steam generator evaporator.

Having left the evaporator, secondary steam enters the steam superheating channels and then at a pressure of 90 atm and temperature of 535°C it is fed to the turbine.

Nuclear district boiler plant instead of process heat boiler one can be used to supply consumers who need only mean and low temperature heat. For example, organic-cooled and moderated reactors of the АРБУС plant reactor type may be used at such plants to ensure the coolant temperature of 300°C at reactor outlet. At this temperature the organic coolant radiolysis and

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pyrolysis will be insignificant, and safe in operation well proved fuel elements canned with aluminium alloy may be used in the reactor.

Alongside with nuclear reactor use for heat and electric energy production they may be used for sea water desalinization in the districts badly in need of drinking, industrial or irrigating water. Central Asia areas are the districts of the kind, the Caspian and Aral Seas being water supply sources. But Central Asia is a part of the USSR well provided with fuel resources (oil, combustible gas) thus it is very difficult for nuclear power to be competitive with power from fossil-fuel fired plants for sea water desalinization.

Preliminary cost estimates show that economically acceptable desalted water costs may be got using about 10000 Mw(t) nuclear reactors with fuel burn-up about 50000-60000 Mwd/t. At the present state of reactor engineering development it is quite possible to get such unit thermal output and nuclear fuel burn-up level. The solution of the problem of nuclear reactor use at desalting plant is facilitated as temperature conditions of fuel element operation are less severe, the coolant temperature required at reactor outlet being about 200-250°C.

Calculations show that in the Soviet Union any reactor of proven design may be used for water desalinization.

2. Technical and economic advisability of self-contained small nuclear heating and power plant use.

Calculations show that alongside with promising large nuclear heating and power plant use in power systems it is economically justified to construct 20-50 Mw nuclear heating and power plants to supply enterprises located in remote north-eastern and eastern areas of the USSR with electric energy and heat.

Disconnection of energy consuming units in remote areas, long distances between towns and industrial enterprises, a great number of relatively small electric energy consumers, hard climatic conditions determine the main tendency in power supply of remote areas in the near future. It is aimed at the development

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of a great number of self-contained (i.e. not united into power systems) sources of electric energy and heat supply.

In the total power balance of the country self-contained small power stations will constitute about 5% for the nearest 10-15 years /2/.

This means that about 20 million kw will be provided from small power stations.

Economic advantages of small nuclear heating and power plants over fossil fuel-fired stations in remote areas are connected with high fossil fuel costs. Coal transport to some districts of the USSR results in rising its price 30-40 times and thus in high fuel cost. While the fuel cost of power from a nuclear heating and power plant does not depend actually on the distance nuclear fuel is transported over but on fuel burn-up and the cost of fuel element fabrication.

Calculations show that for remote areas fuel cost of power from a nuclear heating and power plant is considerably less than that of conventional heating and power plants. Fuel cost fraction of total power cost for thermal power stations located in remote areas is 65-70% due to high transport costs while for 20-50 Mw nuclear power station it is 15-25%. On the whole in some cases it results in lower nuclear power cost compared to conventional one.

However, nuclear heating and power plant capital costs are higher than those of a conventional one with the same output. In the USSR a more expensive power plant is considered to be economically attractive if additional investment of capital in it is justified at the expence of decrease in power cost for the term less or equal to normative one when additional investment is completely justified (eight years).

Technical and economic calculations carried out have shown that a nuclear heating and power plant is economically attractive for use at enterprises consuming much heat in the form of steam and hot water and located in remote areas.

The analysis of net use of energy in industrial processes shows that a large group of enterprises may be picked out among many others with demands for mean and low temperature heat

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(130-200°C) constituting 72-98% of the total energy used. As fossil fuel is not directly used in industrial processes at these enterprises they may be located near raw material deposits, a nuclear heating and power plant provided, if even there is no fossil fuel in this district.

A nuclear heating and power plant use for enterprises of the same type but with different conditions of supply may bring a different gain or not at all.

For example, the comparison of the possibilities to use a nuclear heating and power plant for the Astrahan pulp-board mill and the Krasnovishersk pulp-paper mill has shown that additional investment in the nuclear heating and power plant for the Krasnovishersk mill will by justified for less than eight years, while for the Astrahan one the term will be longer, the former being located in the north of Perm district and consuming black oil which is very expensive because of high transport expenses, and the latter being located in the district where natural gas as cheap fuel is used. Consequently a nuclear heating and power plant use for the Krasnovishersk enterprise may turn to be economically attractive but the use of the same plant for the Astrahan one may be uneconomic.

A small nuclear heating and power plant supplying enterprises located in remote areas with heat and electric energy should meet the following requirements:

a) Control simplicity and constant readiness for operation as the nuclear power and heating plant will be the only source of power supply. Therefore the reactor chosen for the plant should be of the proven type;

b) The possibility of being transportable. The plant should be compact. To save time and money on mounting it should be assembled of separate large blocks made at a mill;

c) Suitability to local conditions. The plant should be anti-seismic and operate in case of ever-frozen ground, air low temperatures, possible lack of water, etc.;

d) The possibility to adjust to large and sharp load changes due to the time of a day or year. The nuclear heating and power plant should be stable in a wide range of power (from 20

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to 100%) and should quickly change power level;

e) Long time interval between refuelings. As it is not desirable to shut down the reactor often, the reactir life-time should be long enough (two-three years);

f) The possibility of changing in a wide range the ratio of electric energy output to heat one and of varying the temperature of the heat generated.

g) The necessity of the coolant (steam or water) being clean from radioactive contamination.

At the present state of reactor engineering development these requirements for a small muclear heating and power plant are quite realistic.

A typical block of a separate 12 Mw(e) nuclear heating and power plant has been developed to meet the needs of enterprises and a small town in a remote district in electric and heat energy.

A thermal uranium-graphite pressure-tube reactor with boiling water as coolant is usedat the nuclear heating and power plant. In the main the reactor design is similar to that of the Beloyarsk nuclear power station after I.V.Kurchatov /1/.

The safe operation of the uranium-graphite reactor under boiling conditions is confirmed by operating experience of the First Nuclear Power Station of the USSR /5/.

The principal scheme of such a nuclear heating and power plant is shown in Fig.4.

Steam-water mixture is piped from every fuel element channel to the separator. Steam from the separator is fed to the turbogenerator and water is transported to the circulating pump. The steam extracted from the turbine passes to the boiler where water circulating in the district heating network is heated and to the regenerative preheaters of feed water. The condensate from the boiler passes to low pressure preheaters and then to the turbine condenser.

According to the diagram of heat and electric energy use the operation of a nuclear reactor at a heating and power plant must be adjusted to great changes in heat and electric energy use depending on the season or time of day.

Day diagrams of heat production at a nuclear heating and power plant in winter and summer show that the nominal thermal

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power of the reactor-turbogenerator unit should be 60 Mw.

In this case the unit power is 12 Mw(e) and about 29 Mw(t). Such a unit can generate 17 Mw(e) at an initial steam pressure of 40 atm and the turbine operating with a condenser.

Thus, the preliminary investigation of the problem shows that developing on a wide scale district heating and centralized heat supply in the USSR large nuclear reactor uses for combined generation of heat and electric energy as well as for heat generation only are a promising trend in the radical improvement of fuel-power balance.

In addition, the use of separate small about 20-50 Mw nuclear heating and power plants for heat and electricity supply of enterprises located in remote areas is economically justified in a number of cases.

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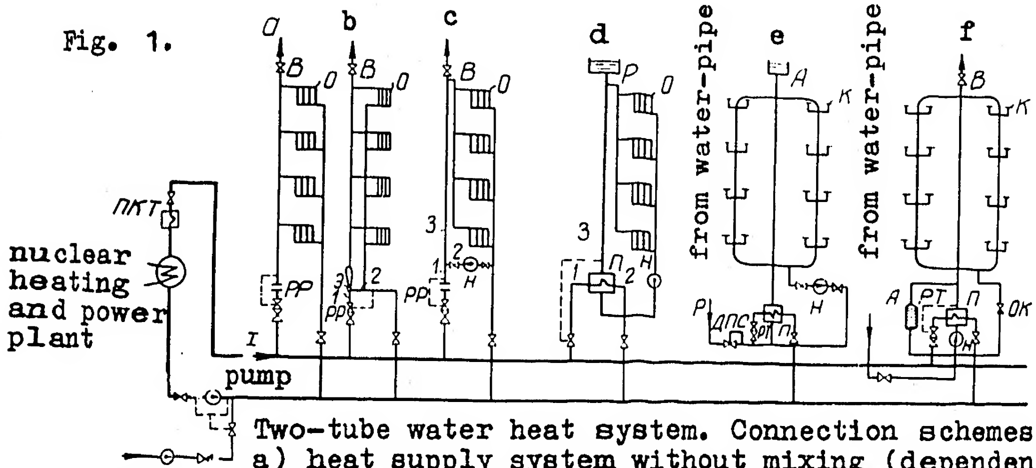
Fig. 1.



Two-tube water heat system. Connection schemes of: a) heat supply system without mixing (dependent scheme); b) heat supply system with jet mixing (dependent scheme); c) heat supply system with pump mixing (dependent scheme); d) heat supply system (independent scheme); e) hot water supply system with upper storage; f) hot water supply system with bottom storage.
A – hot water storage; B - air (relief) cock; K – tap; H - pump; O - radiator; OK - non-return valve; П - preheater; P - expansion tank; РДПС - pressure regulator; PP - flow rate regulator; PT – temperature regulator; Э - elevator.

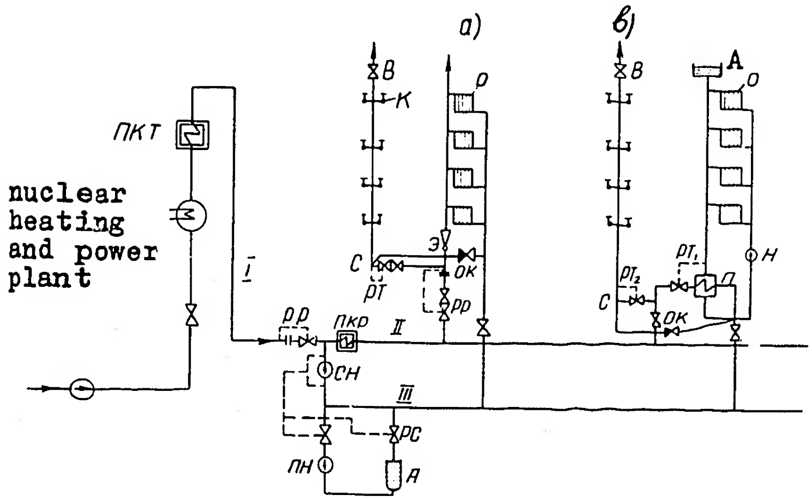


Fig.2. Water system with single transient and two-tube distribution network.
I - transient main; II, III - heat distribution network. Schemes of connecting heat and hot water supply systems: a) dependent scheme, integrating control; b) independent scheme, non-integrating control; A - storage; B - air (relief) cock; K - tab; H - pump; O - radiator; П - preheater; ПН - make-up pump; РП - make-up regulator; PC - dumping regulator; PP - flow rate regulator; PT - temperature regulator.

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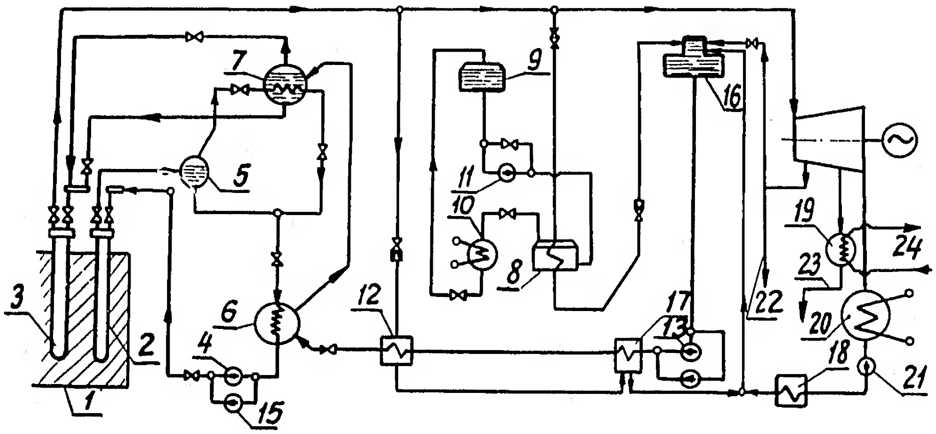

Fig.3. Principal flow sheet of large nuclear heating and power unit with net electric output of 100 Mw.
1 - reactor; 2 - evaporating channel; 3 - steam superheating channel; 4 - circulating pump; 5 - steam drum; 6 - preheater; 7 - evaporator; 8 -condenser; 9 - reactor shut-down cooling tank; 10 - steam cooler; 11 - condensate pump; 12 - superheating regulator; 13 - feed pump; 14 - secondary circuit emergency pump; 15 - primary circuit emergency pump; 16 - deaerator; 17 - high pressure preheaters (ПВД); 18 - low pressure preheaters (ПНД); 19 - boilers; 20 - condenser; 21 - condensate pump; 22 - steam to high pressure preheater; 23 - steam to low pressure preheater; 24 - heat network.

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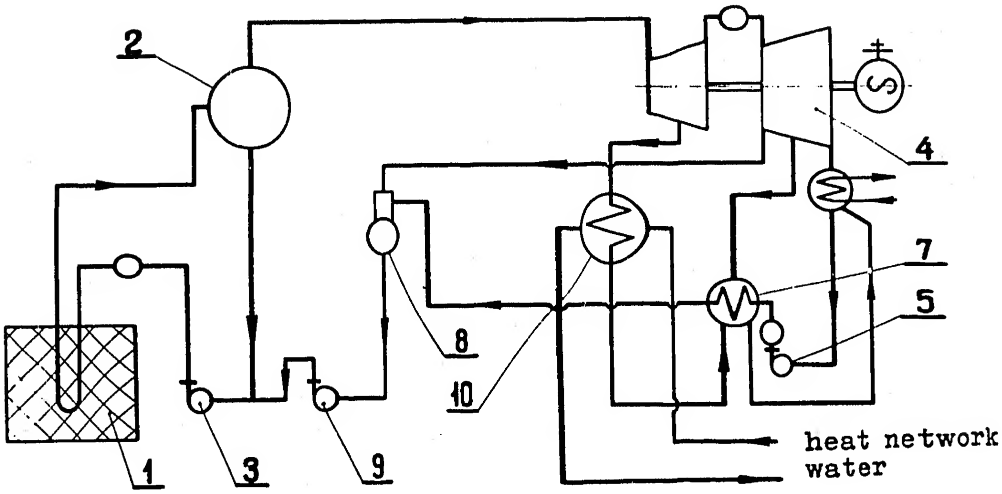

Fig.4. Principal flow sheet of self-contained small nuclear heating and power unit with net electric output of 12 Mw.
1 - reactor; 2 - separator; 3 - circulating pump; 4 - turbogenerator; 5 - condensate pump; 6 - condensate purification unit; 7 - low pressure preheaters; 8 - deaerator; 9 - feed water pump; 10 - boilers.

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